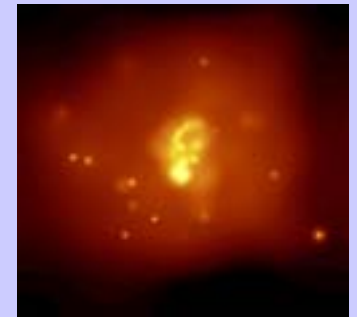
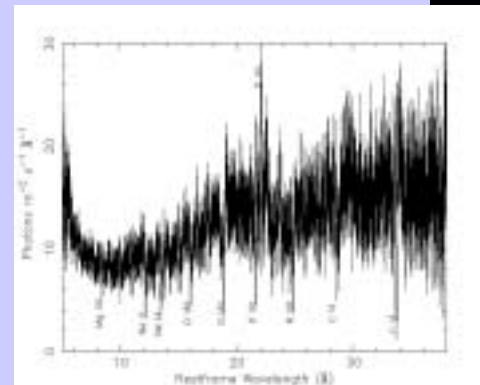
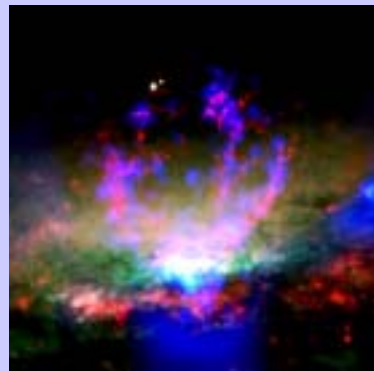
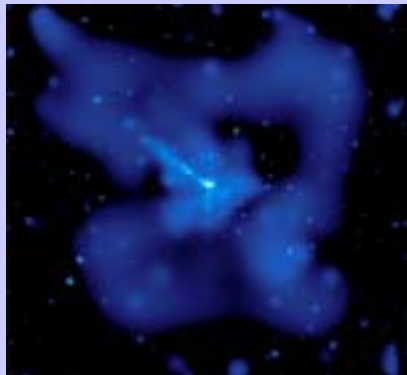
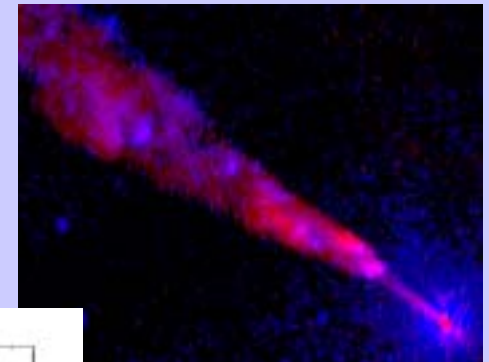
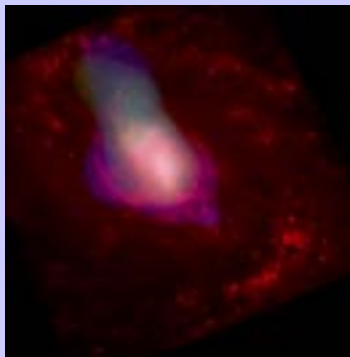


Observing Active Galaxies with Chandra and XMM

Kim Weaver

NASA GSFC



AGN Statistics

Chandra: 980 observations of AGN - 23% of total time

XMM: ~500 observations of AGN - ~20% of observations

Papers in refereed journals as of 6/03: Chandra - 85, XMM - 58

Fe K lines	Chandra (3)	xmm (13)
Sy1s/warm absorbers	Chandra (13)	xmm (11)
NLSY1s	Chandra (2)	xmm (7)
classic QSO studies	Chandra (10)	xmm (9)
quasar jets/radio gals	Chandra (30)	xmm (1)
BL Lacs/Blazars	Chandra (1)	xmm (5)
Seyfert 2s	Chandra (11)	xmm (5)
LLAGN/stb-AGN	Chandra (9)	xmm (2)
ULIRGs	Chandra (6)	xmm (5)

Active Galactic Nucleus

LLAGNs

Iron Lines

Fe K α from **Disk**/BLR/NLR/Torus

ULIRGs

NLR 50-100 pc

Scattering
gas: tens of
pc - kpc

$N_H \sim 10^{21} - 10^{22} \text{ cm}^{-2}$

Reflecting gas:

$N_H \sim 10^{24} \text{ cm}^{-2}$

Torus/starburst
> ~ pc scale

Absorbing gas:
~ light-days

BLR

Warm absorber

$N_H \sim 10^{20} - 10^{23} \text{ cm}^{-2}$

Seyfert 2s

Seyfert 2

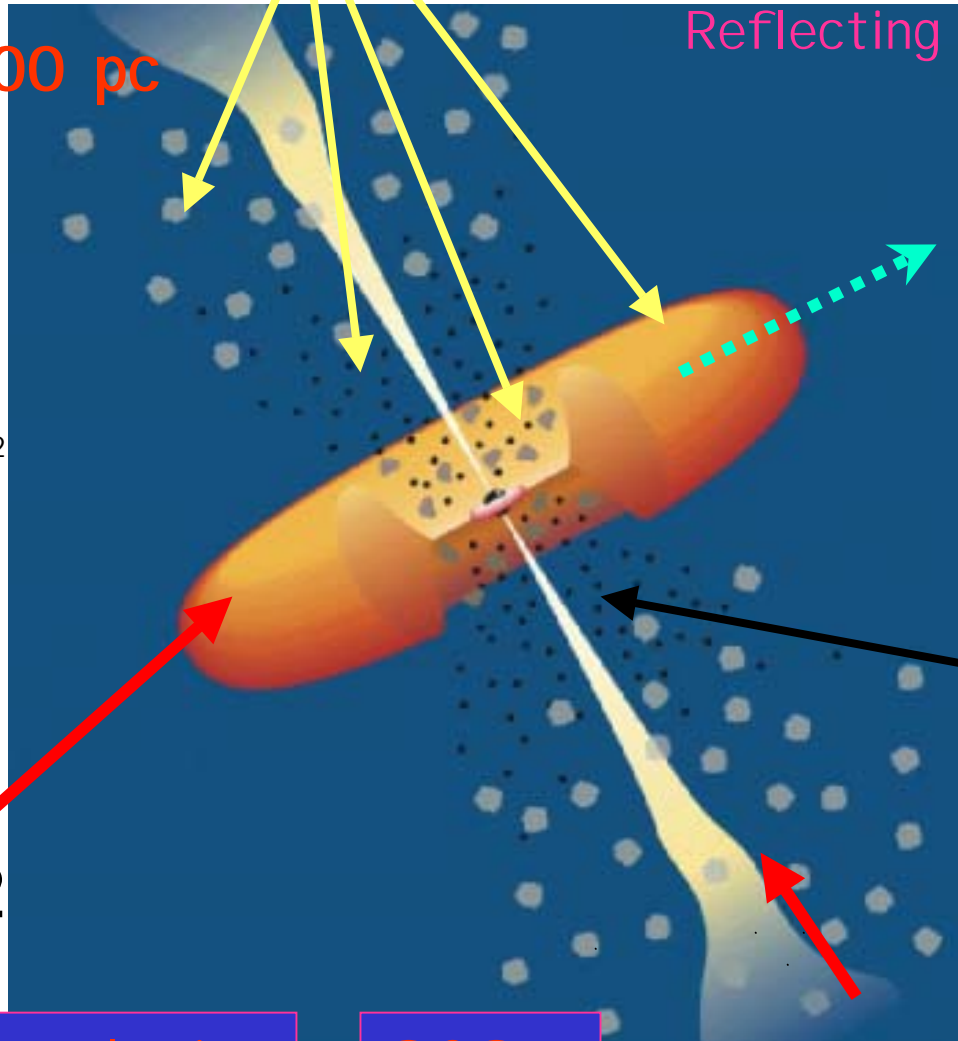
NLSY1s

BL Lacs

Jets/radio galaxies

QSOs

Seyfert 1

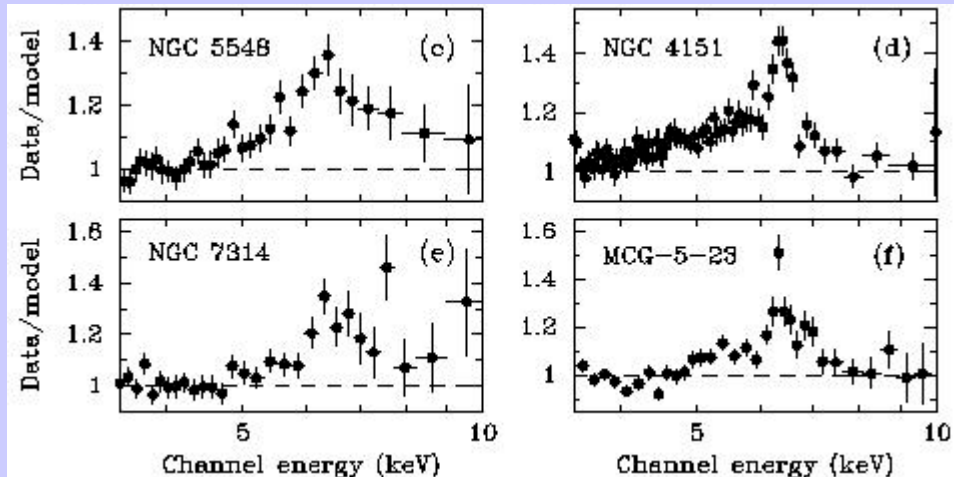
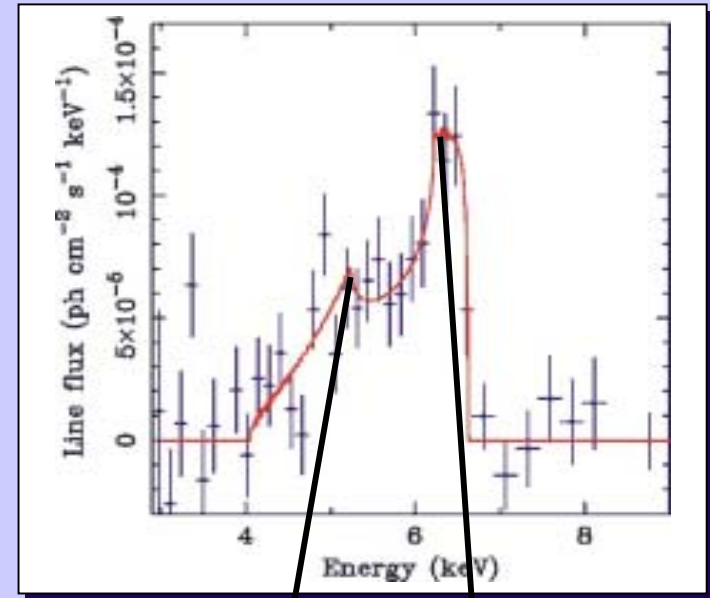


Iron line Diagnostics

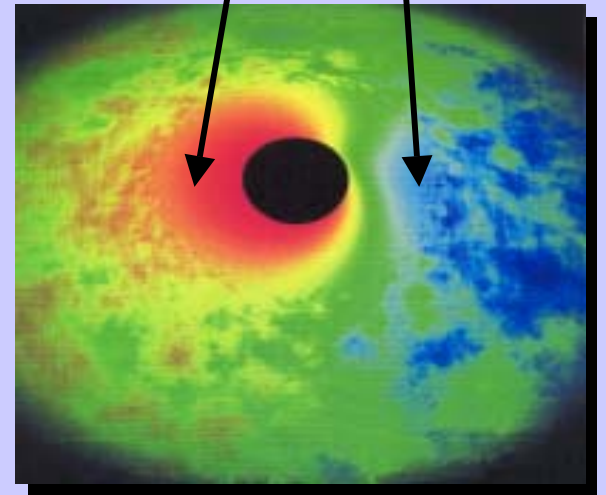
Seyfert galaxies are excellent laboratories for studying the accretion flow in AGN

- X-ray reflection from optically thick matter
- Fe $K\alpha$ fluorescence emission lines
- Fe $K\alpha$ line has multiple components (from accretion disk, torus, BLR, NLR)
- Lines are variable (Weaver, Gelbord & Yaqoob 2000, ASCA)
- Probe effects of general relativity

MCG-6-30-15 Tanaka et al. 1995



ASCA line profiles - Yaqoob, Weaver 1996



What have we seen with Chandra and XMM?

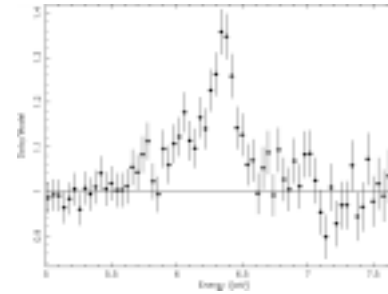
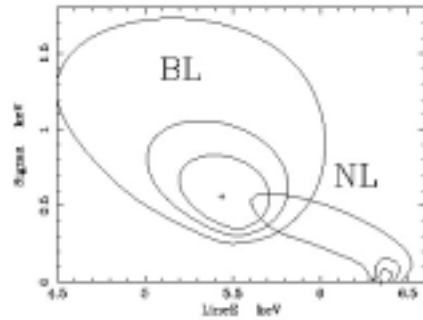
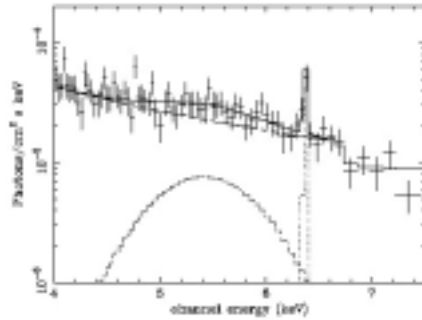
Narrow line at 6.4 keV: Fairall 9 (Sy1), IC 4329A (Sy1), NGC3227 (Sy1), ESO 141-G55 (Sy1), Mrk 6 (Sy1.5), NGC 7469 (Sy1), NGC 5548 (Sy1, FWHM~4,000 km/s), NGC 4151? (Sy1): *EWs range from ~40 to 200 eV. Also Fe K edge is often detected.*

Broad line: Mrk 335 (NLSy1), Mrk 766 (NLSy1), Mrk 231 (BAL QSO, FWHM~18,000 km/s), MCG-6-30-15 (Sy1), Q0056-363 (QSO, FWHM~25,000 km/s), Mrk 766 (NLSy1)

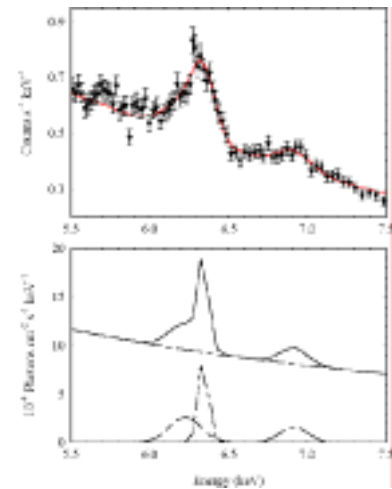
Multiple components with a narrow line at 6.4 keV: Mkn 509 (Sy1), NGC 3783 (Sy1), MCG-5-23-16 (Sy1.9, broad FWHM~40,000 km/s), IRAS 13349+2438 (NLSy1), Mrk 205 (QSO), NGC 3516 (Sy1), NGC 5506 (Sy 1.9), NGC 3516 (Sy1), Mrk 359 (NLSy1)

Multiple narrow lines: NGC 7314 (Sy1), NGC 7213 (Sy1)

IRAS 13349 - NLSy1 (Longinotti et al. 2003) Fe K Gallery

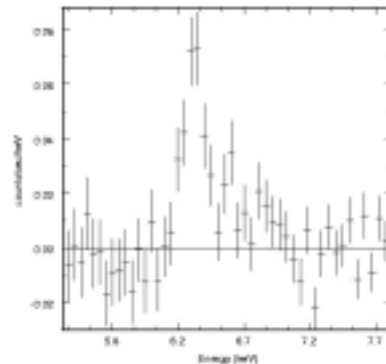
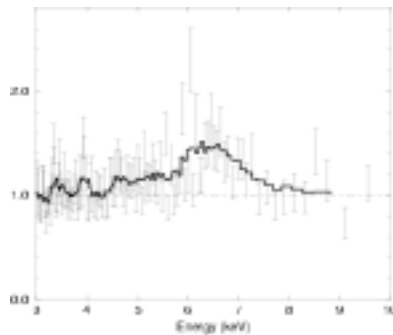


MCG-5-23-16 - Sy 1.9
(Dewangan et al. 2003)

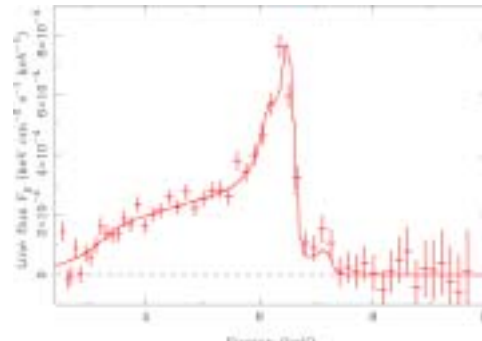


NGC 3783 - Sy1
(Blustin et al. 2002)

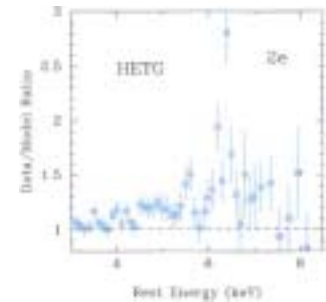
Mrk 335 - NLSy1
(Gondoin et al. 2002)



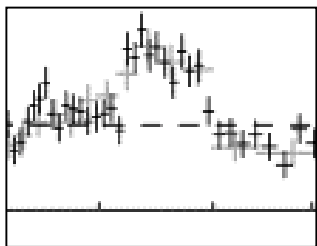
NGC 7213 - Sy1
(Bianchi et al. 2003)



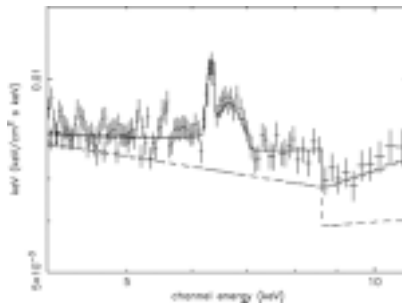
MCG-6-30-15 - Sy1 (Fabian
& Vaughan 2003)



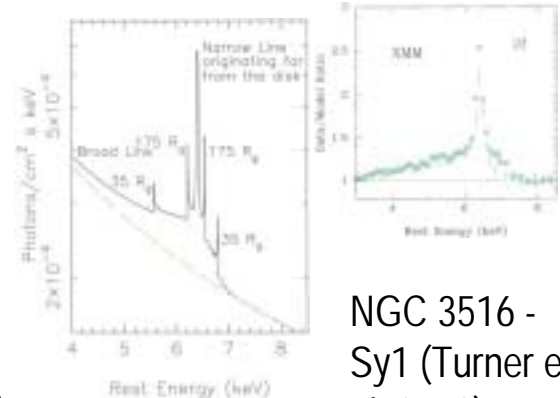
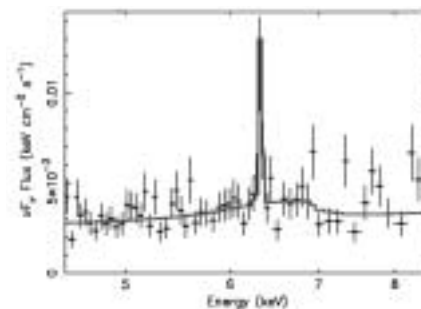
NGC 3516 -
Sy1 (Turner et
al. 2002)



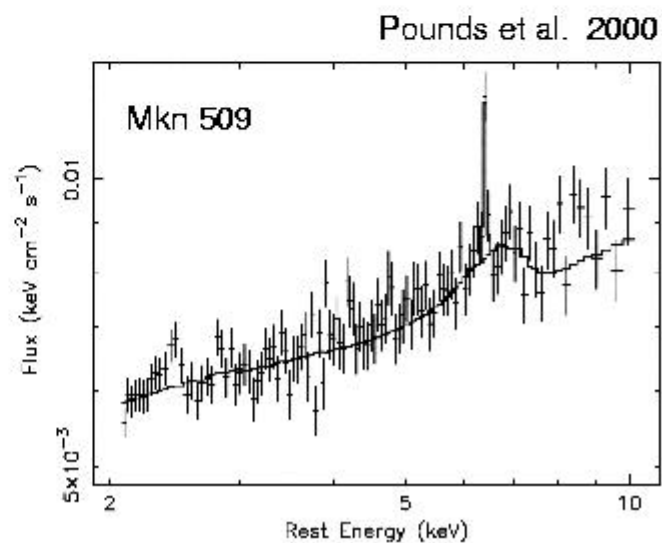
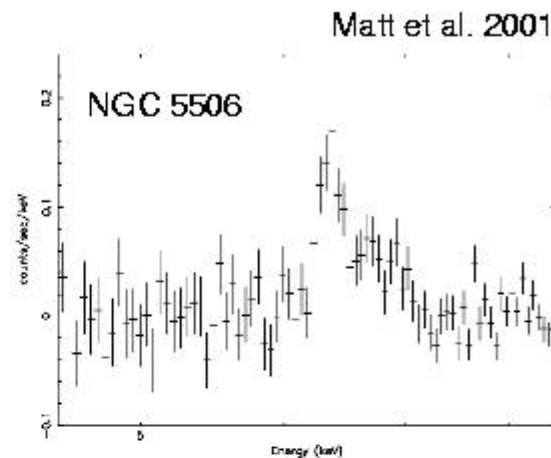
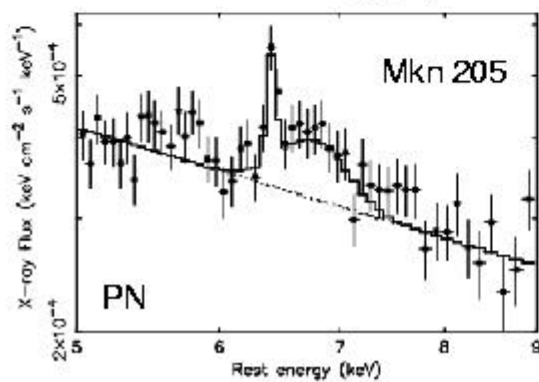
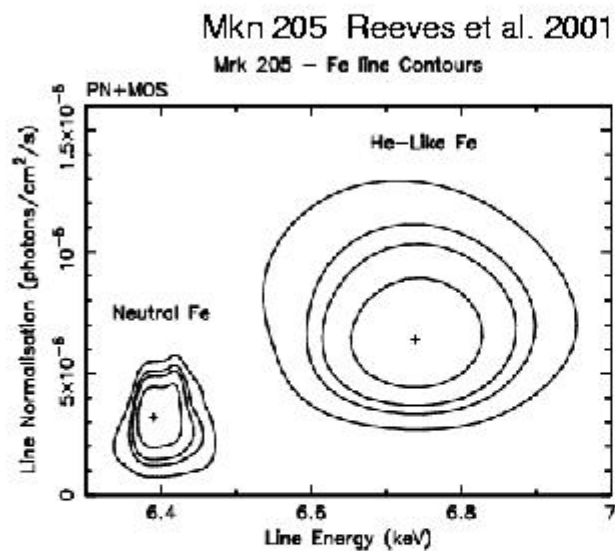
Mrk 766 - NLSy1 (Pounds et al. 2003)



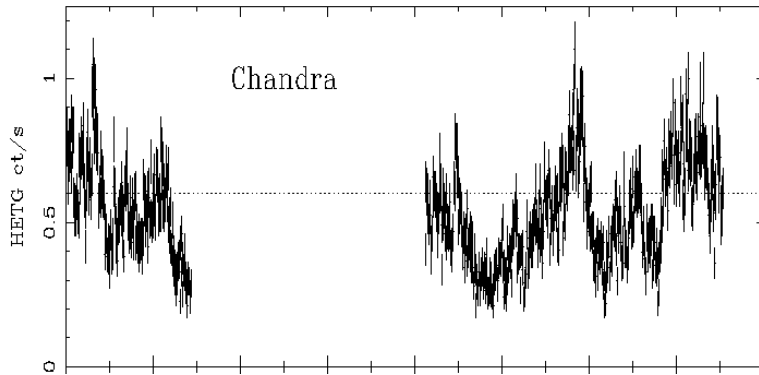
Mrk 359, NLSy1 (O'brien et al. 2001)



He-like Fe Lines in XMM Data

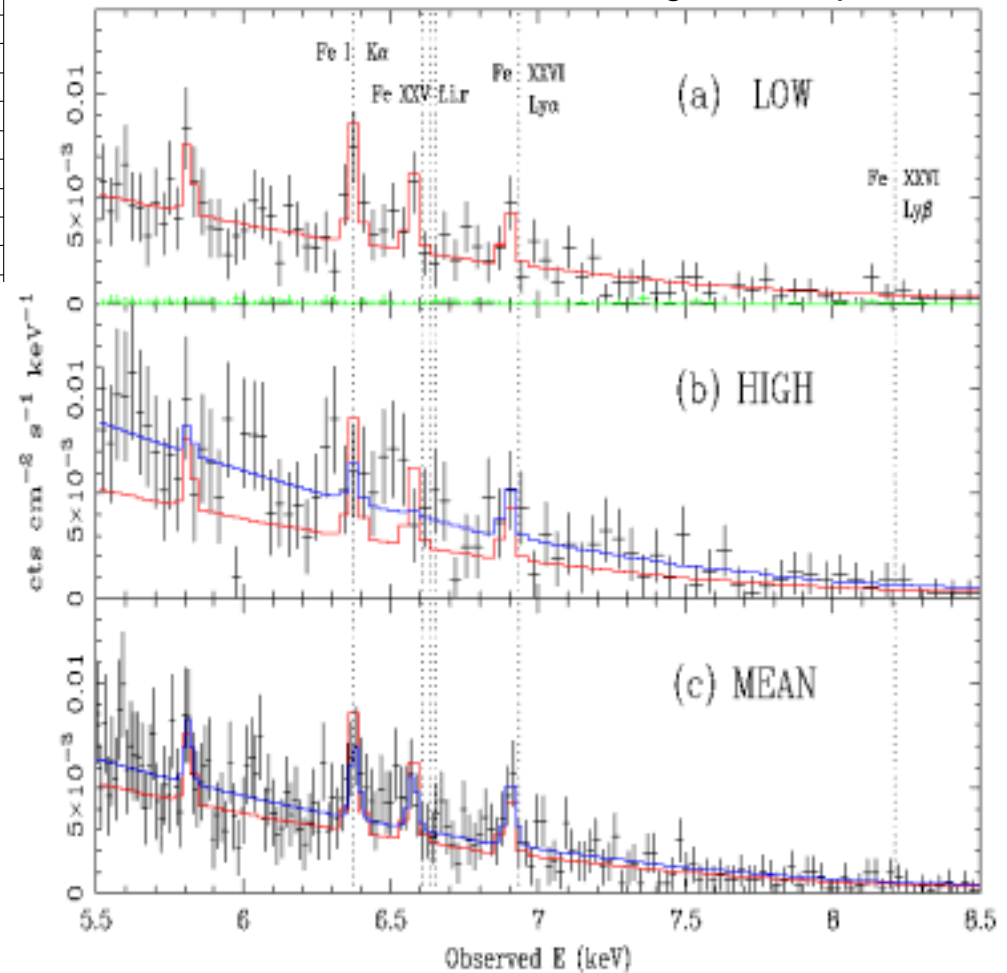


NGC 7314: Fe XXV & Fe XXVI narrow, rapidly variable, unresolved lines from an accretion disk



- He-like & H-like lines are redshifted, Fe I K line is not.
- Redshift is ~ 1500 km/s, greater than systemic and statistical uncertainty.
- Is He-like line f, i, or r? HEG cannot resolve.
- Redshift consistent with H-like line if forbidden.
- Ionization balance varies in less than 13,000 s. Lines from close to source.

Chandra HEG low, mean and high-state spectra



Yaqoob et al. 2003

Narrow Line Seyfert 1 galaxies

More rapid X-ray variability and steeper X-ray spectra than broad line Seyfert 1s.

- Soft excesses - continuum components?
- Little absorption - highly ionized gas
- Fe K lines at higher ionization stages
- Rapid and unusual spectral variability
- Generally - ionized reprocessing
- Fe K absorption features?
- Unusual spectral shapes (high and low states)

Black holes with high accretion rates -> ionized disk plus circumnuclear gas

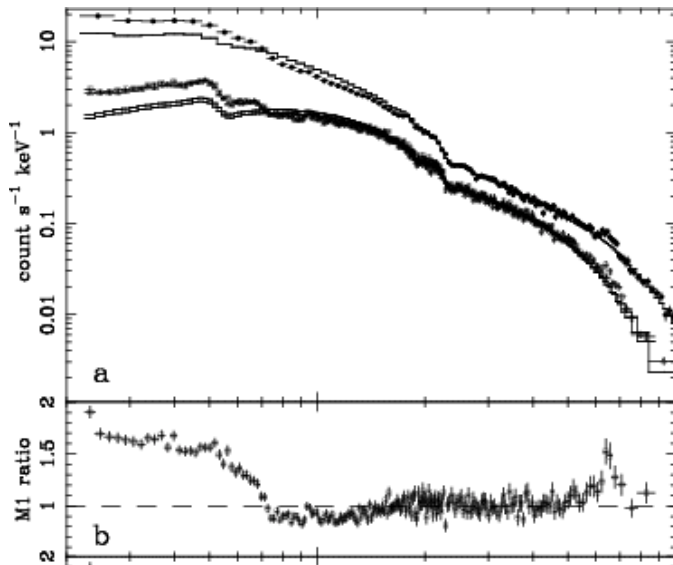
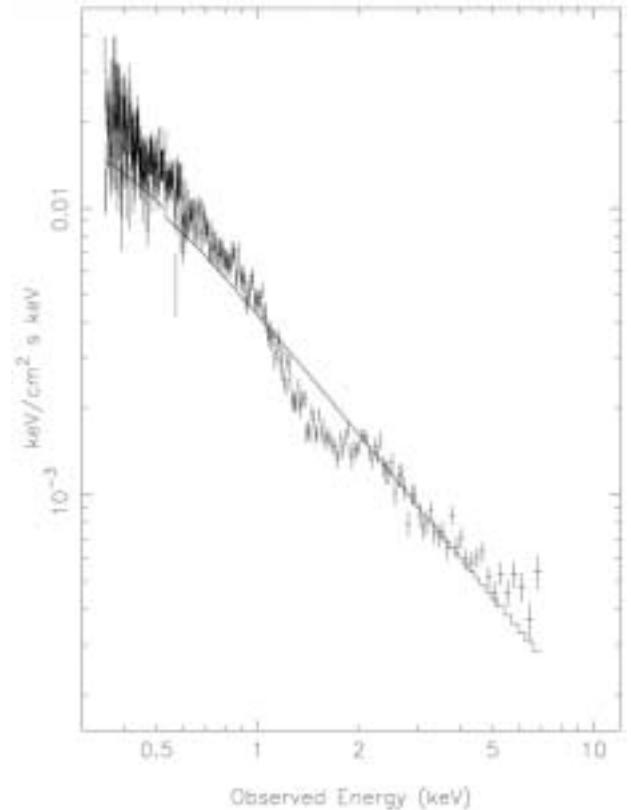
Ton S180

Chandra - Turner et al. ApJ 2001; XMM - Vaughan et al. MNRAS, 2002

Strong, broad and smooth soft excess. Continuum reprocessing of X-rays from ionized disk or a blend of lines from ionized disk. $M_{\text{BH}} \sim 4 \times 10^7$

Fe $K\alpha$ near 7 keV. Fe XXV-XXVI. Broad, $\sigma = 0.5$ keV with XMM, ionized reflection from an ionized disk w/ an inclination of ~ 65 degrees.

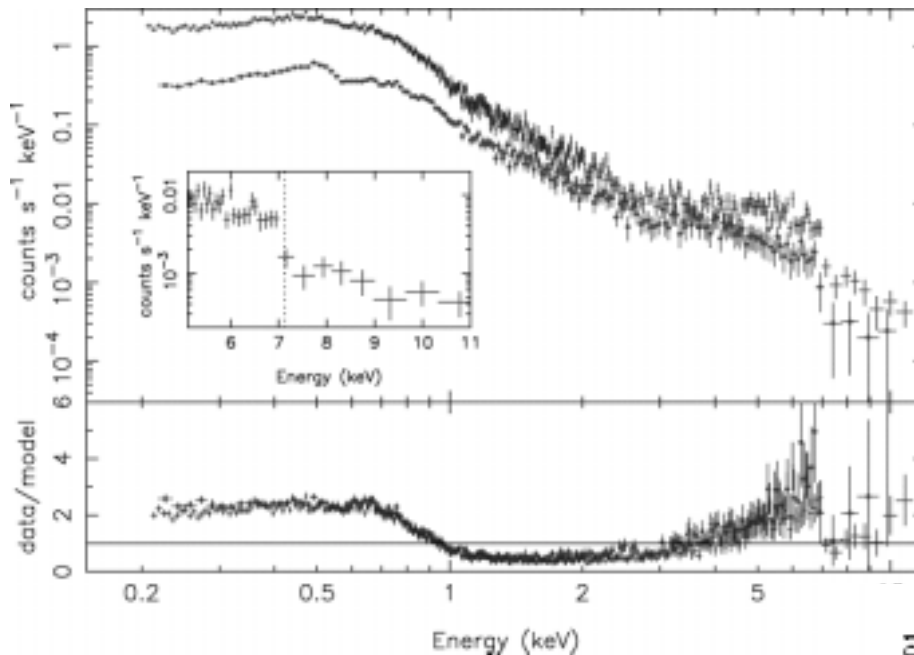
Featureless soft excess requires a highly ionized disk while Fe K region requires moderate ionization (no ionized Fe K edge).



Mrk 766

Page et al. 2001, A&A

Broad Fe $K\alpha$ line. Soft excess below 0.7 keV. Medium energy component is more variable than the soft excess.



1H 0707 - 49

Sharp feature at ~ 7 keV. Seen in other NLSY1s. No narrow Fe $K\alpha$ line. Neutral absorption (partial covering) or ionized disk reflection?

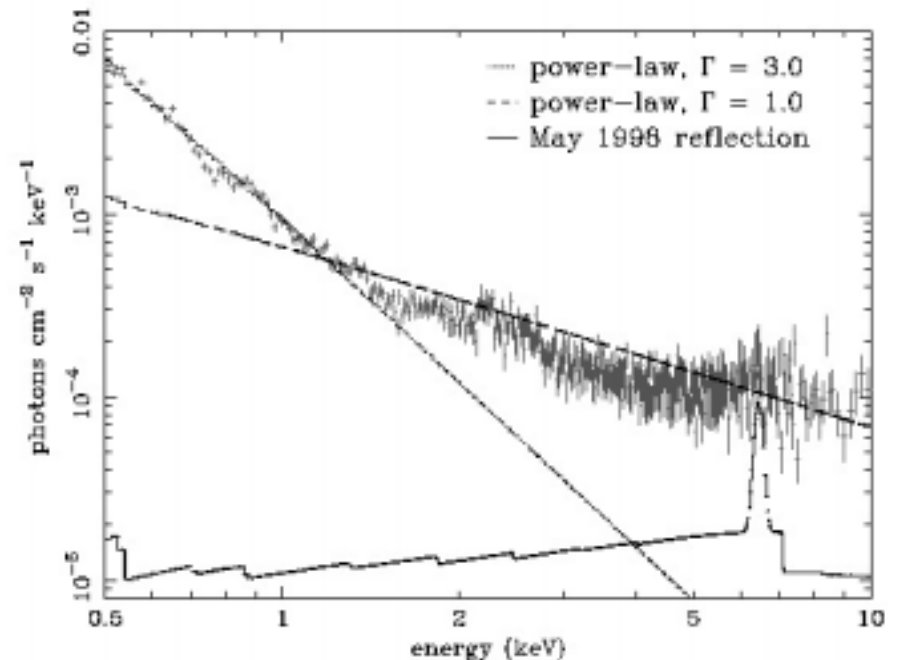
Boller et al. 2002, MNRAS

NGC 4051

Low-flux state

Correlated soft and hard x-ray lightcurves - hard X-rays are not pure reflection.

Uttley et al. astro-ph/0306234



Seyfert 1s, Warm Absorbers

Soft X-ray features probe: gas kinematics, excitation mechanisms, gas geometry, temperature, density, transport (inflow/outflow), how BH is fueled

- Ionized X-ray absorption lines, variable absorption
- narrow lines but some are resolved, blueshifted
- UV counterparts in many cases
- weak emission lines
- mixture of partially ionized and neutral absorbing gas

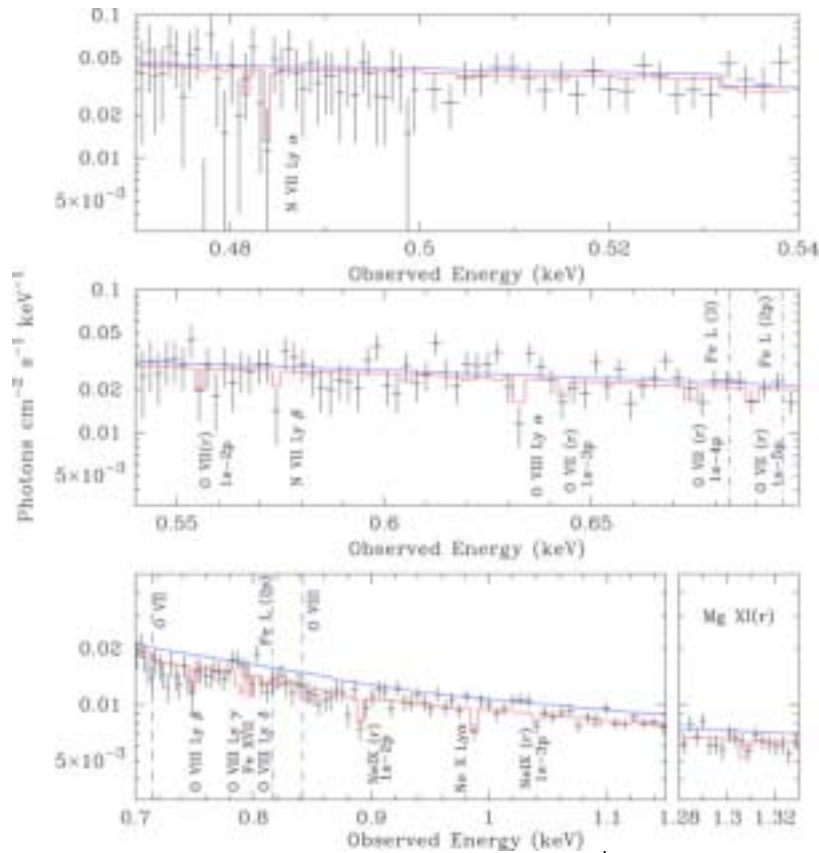
Conclude:

Multiphase warm absorber is an expanding shell of gas with outflow velocities of ~ 500 km/s and $N_H \sim \text{few } 10^{21} - 10^{22} \text{ cm}^{-2}$ Radius is greater than a few light days.

Some difficulty connecting x-ray / UV absorbers. NGC 7469: highest ionization phase of x-ray absorber is identified with low-velocity phase of the UV absorber

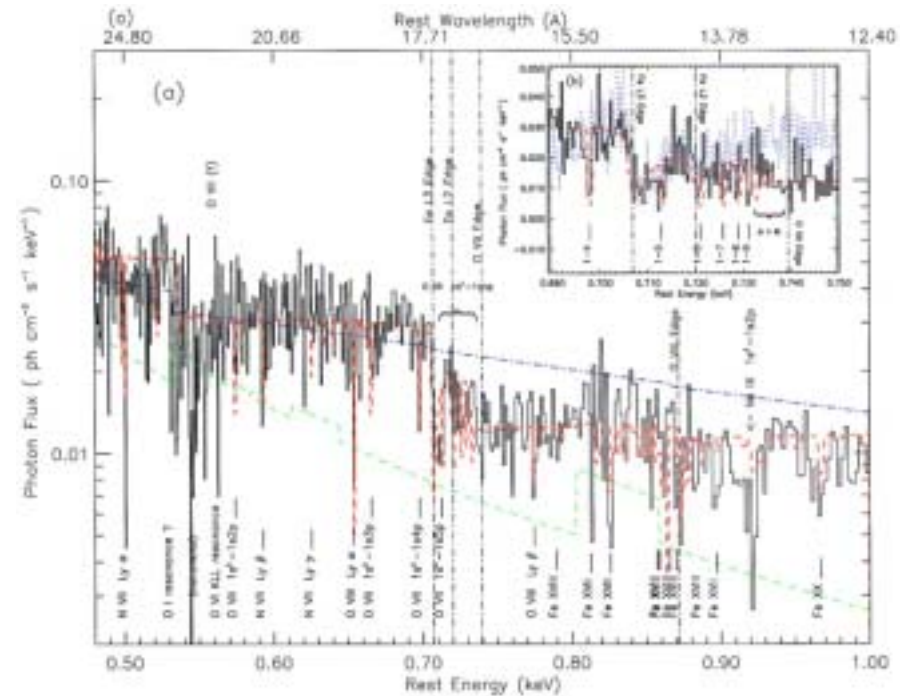
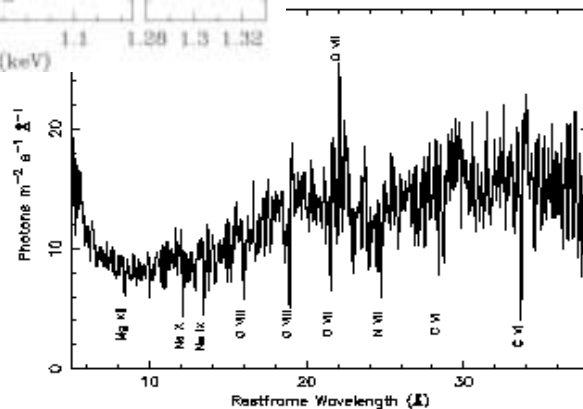
Low mass loss compared to the accretion rate. Outflow rates are $\sim 10^{-5} - 10^{-4}$ solar masses per year.

Soft X-ray Spectra:

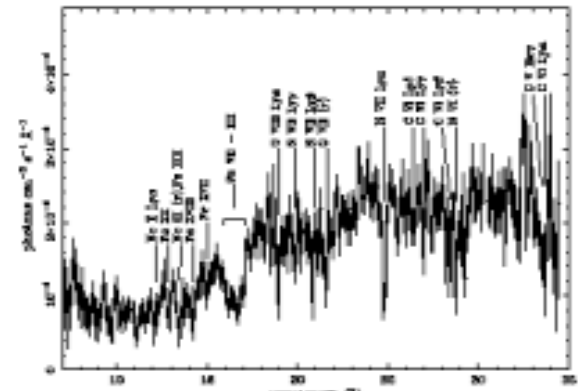


Markarian 509; Chandra;
Yaqoob et al. 2003

NGC 5548; Chandra
Kaastra et al. 2000, A&A



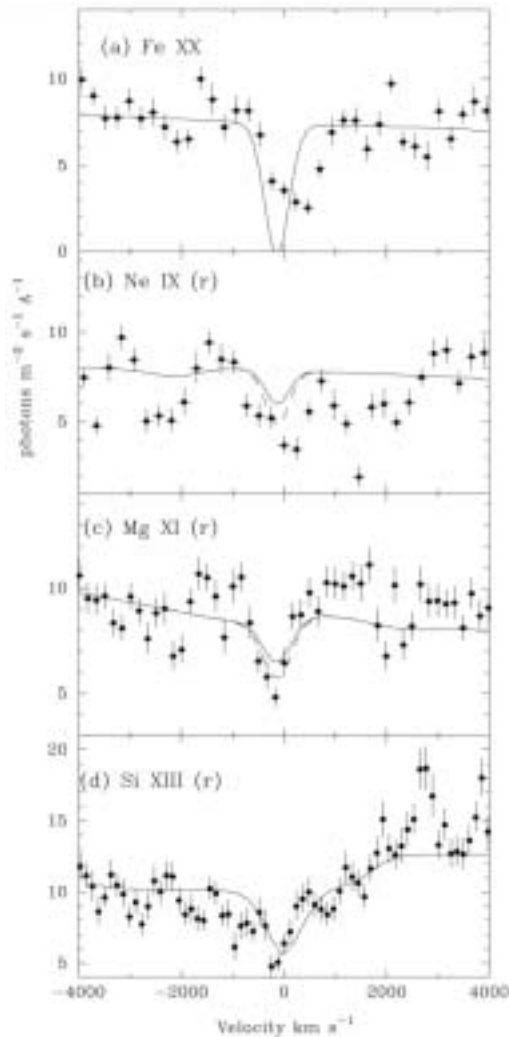
MCG-6-30-15; Chandra, Lee et al. 2001



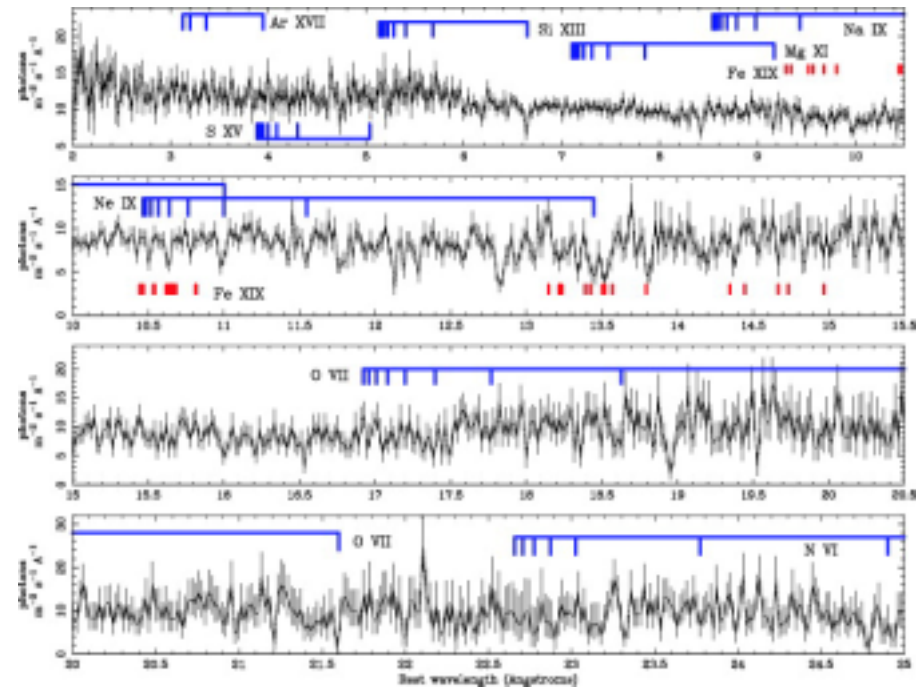
IRAS 13349; XMM
Boller et al. 2003, MNRAS

NGC 4593

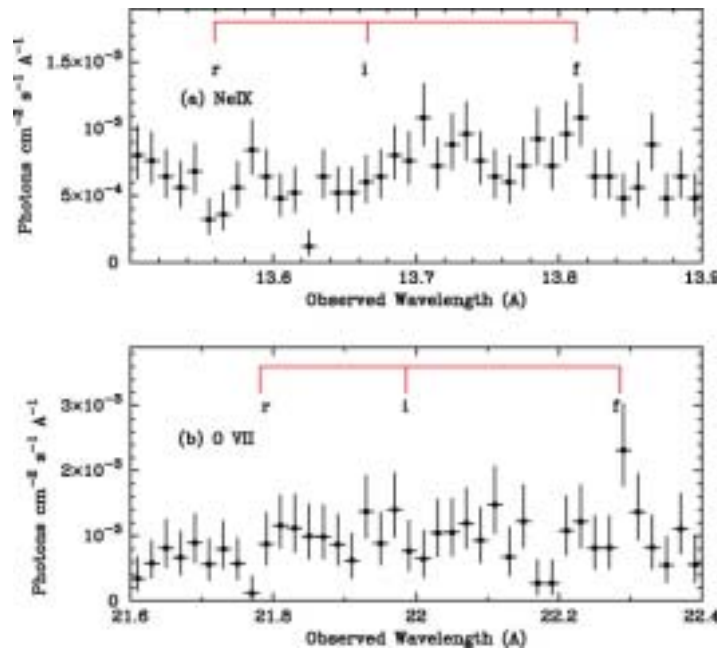
McKernan et al. 2003, ApJ



Velocity
profiles



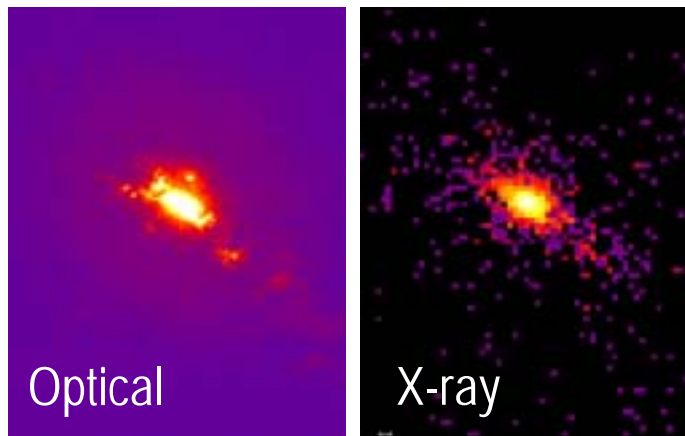
Chandra MEG
photon spectrum



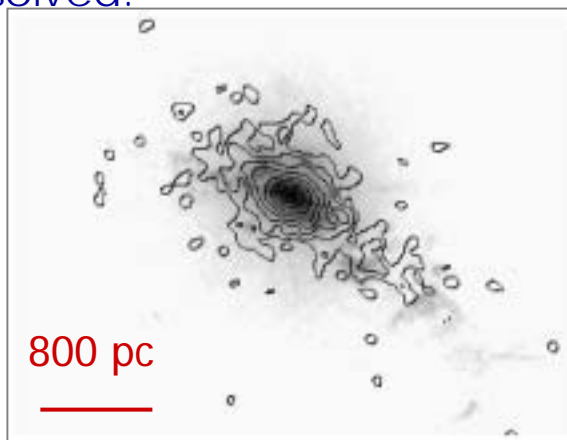
He-like Ne
and O triplets

NGC 4151 - Extended X-rays

Ogle et al. 2000, ApJ, 545, L81

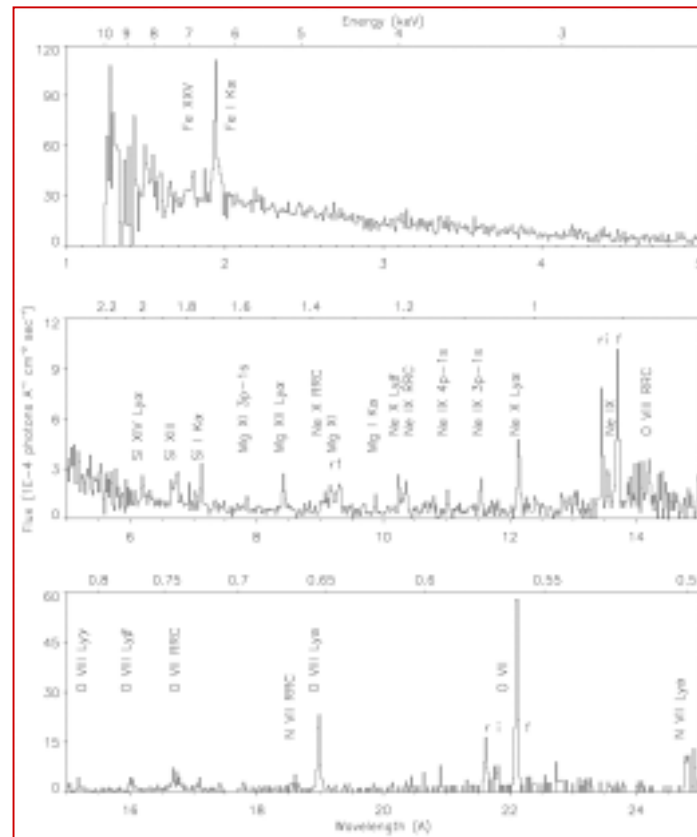


70% of soft X-ray emission is resolved.



Chandra contours overlaid on HST [O III] 5007 image.

Chandra HEG & MEG spectra.



Spectrum dominated by narrow lines from a spatially resolved (1.6 kpc), highly ionized nebula.

X-ray lines have similar velocities, widths, and spatial extent to the optical lines.

The X-ray NLR is composite, consisting of photoionized ($T = 3 \times 10^4$ K) and collisionally ionized ($T = 10^7$ K) components.

Seyfert 2 Galaxies

Absorption: low ionization absorption through edge of torus or circumnuclear starburst, up to a fully blocked nucleus ($N_H \sim 10^{24} \text{ cm}^{-2}$)

Extended x-ray emission - photoionization - consistent with size of scattering mirror and optical NLR. Size tens of pc to kpc. $N_H \sim 10^{21}$ - 10^{22} cm^{-2}

AGN-driven outflows hundreds of pc across. Clouds may be shock-heated by the nuclear outflow. Velocities are hundreds of km/s

Fe K lines from torus, scattering zone - some show extended Fe K emission. Fe K line EWs up to several keV

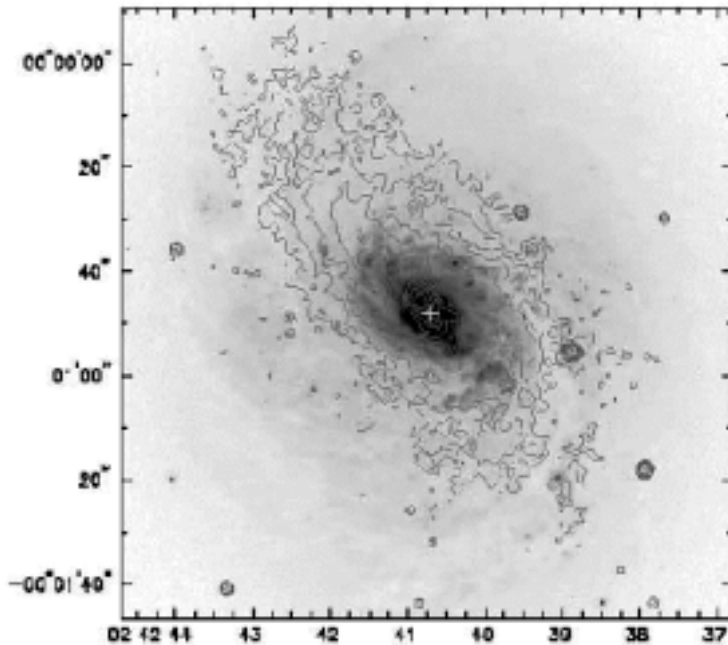
Hard x-ray spectra dominated by reflection for $N_H > 10^{24} \text{ cm}^{-2}$

Properties tend to be consistent with unified model, but starbursts have introduced a new wrinkle!

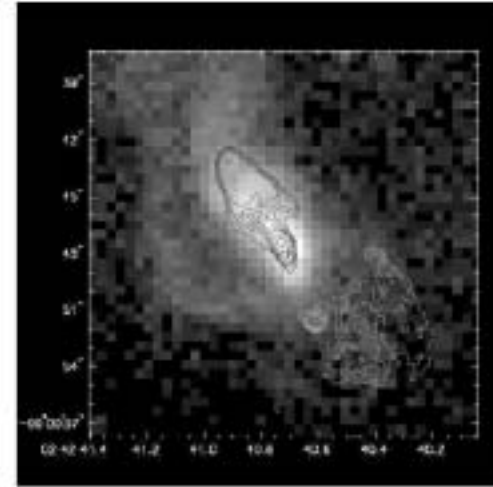
NGC 1068

Young, Wilson & Shopbell 2001

D=23 Mpc, 1 arcsec=110 pc



Chandra contours on optical continuum image. Cross marks the position of the radio source.



Chandra image of the galaxy center superposed on VLA 6 cm radio contours.

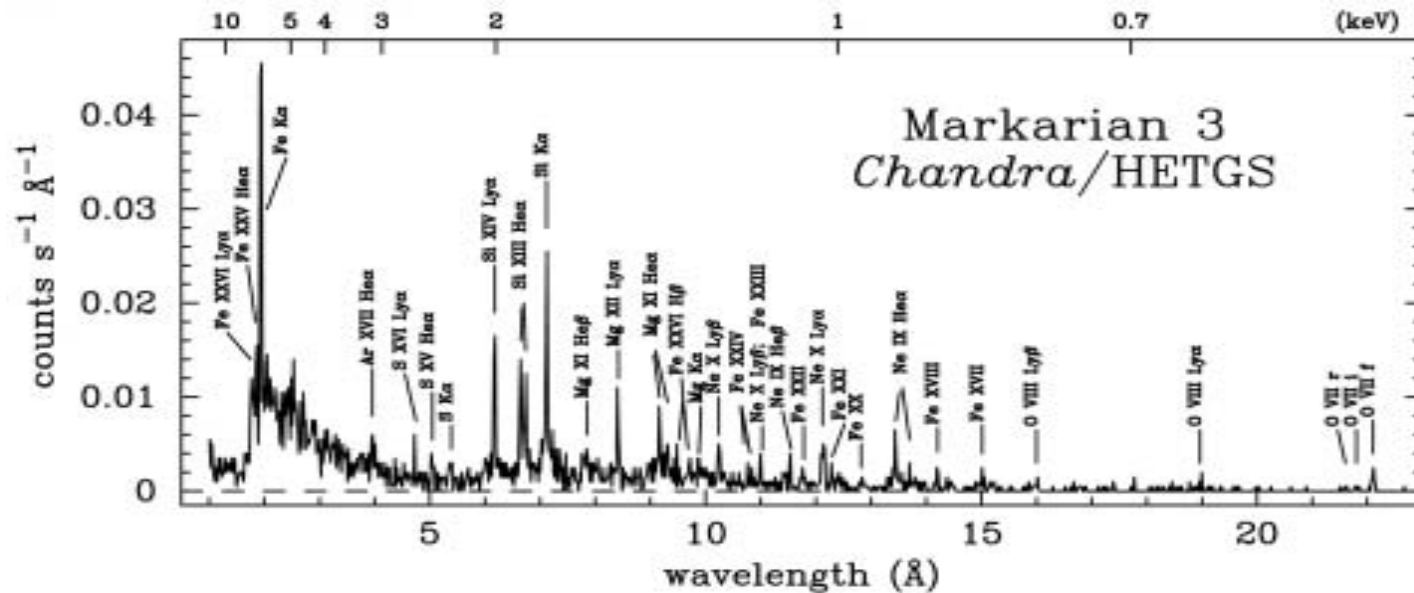
X-ray emission extends 5" (550 pc) to the NE and coincides with the NE radio lobe and gas in the NLR.

Spectrum is photoionization and fluorescence.

Hard X-ray emission (+ Fe K) extends 20" (2.2 kpc) NE and SW of the nucleus.

Markarian 3

Sako, Kahn, Paerels, Liedahl 2000, ApJ, 543, L115

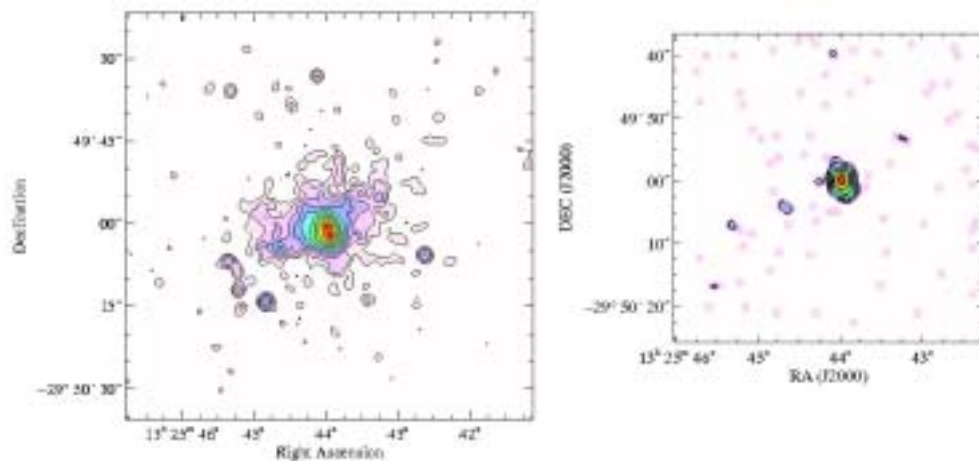


Combined HEG and MEG 1st-order spectrum

- Hard X-rays - reflection in a cold medium.
- Soft X-rays extended along [O III] ionization cone. Recombination and photoexcitation from a warm photoionized medium. Negligible emission from a collisionally ionized plasma.
- Spectral properties consistent with a Seyfert 1 galaxy viewed edge on.

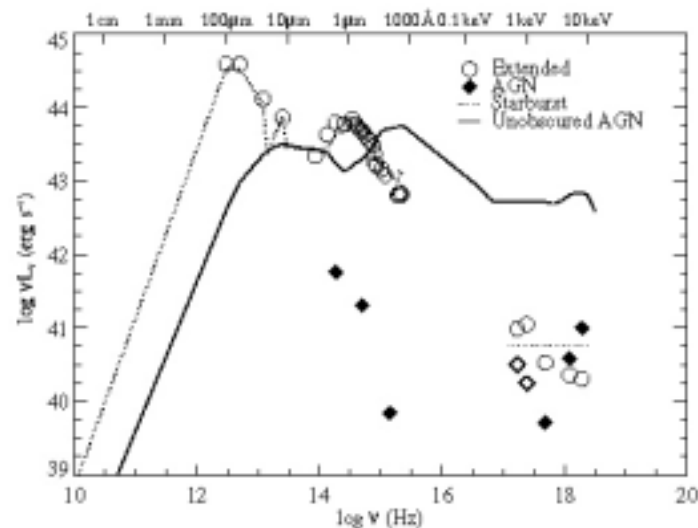
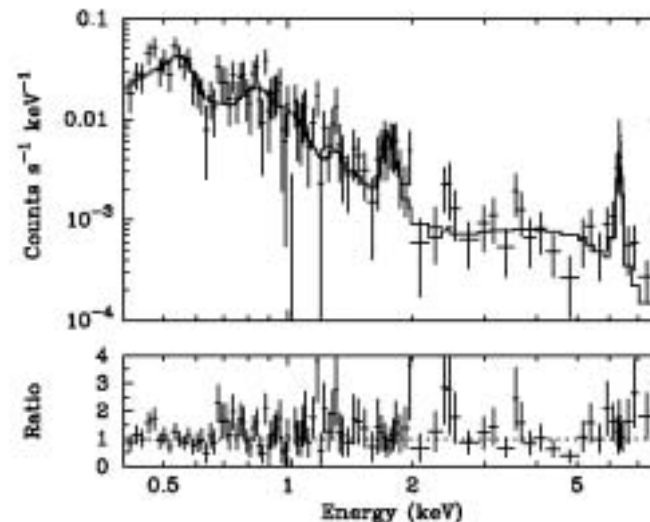
NGC 5135 - Cohabitation of an AGN and Starburst

Levenson, Weaver & Heckman 2003



Chandra soft and hard x-ray images

- Both the AGN and starburst contribute significantly to the x-ray emission.
- AGN obscured by $N_H > 10^{24} \text{ cm}^{-2}$, much of it due to the starburst
- Below 10 keV nearly all of the emergent luminosity is due to SF, not the AGN



NGC 5135 SED

QSOs - Classic

Broad absorption line quasars - ionized, relativistic broad x-ray lines

Intrinsic absorption - do not always see this in spite of earlier claims

Evolution of spectral shapes - stats still accumulating

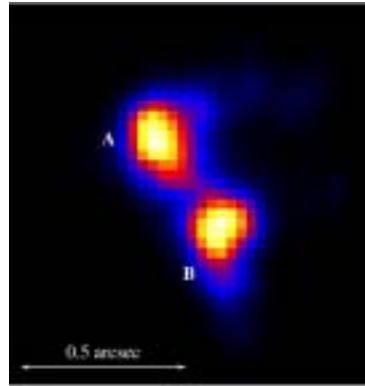
Fe K lines - 6.4 keV lines tend to be weak features: PKS 0537-286 has Fe K with EW of ~ 33 eV; upper limits in some other cases. Also ionized lines (Mrk 205)

Quasar 2s - reflection-dominated x-ray spectra with large EW Fe K lines

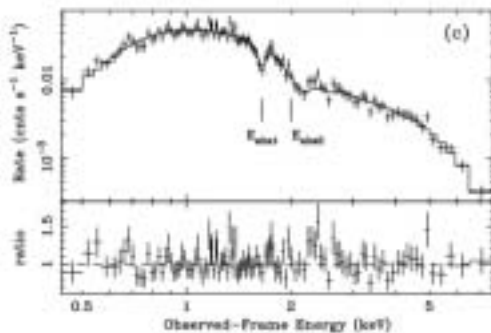
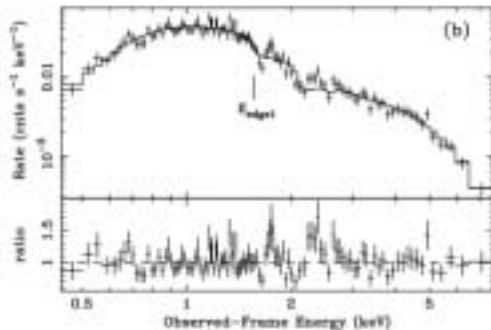
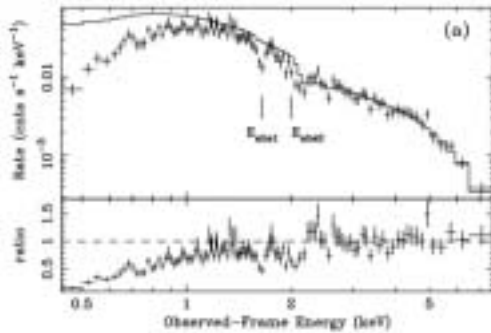
Search for absorption from the IGM - mostly upper limits so far

Absorption in the BAL QSO APM 08279

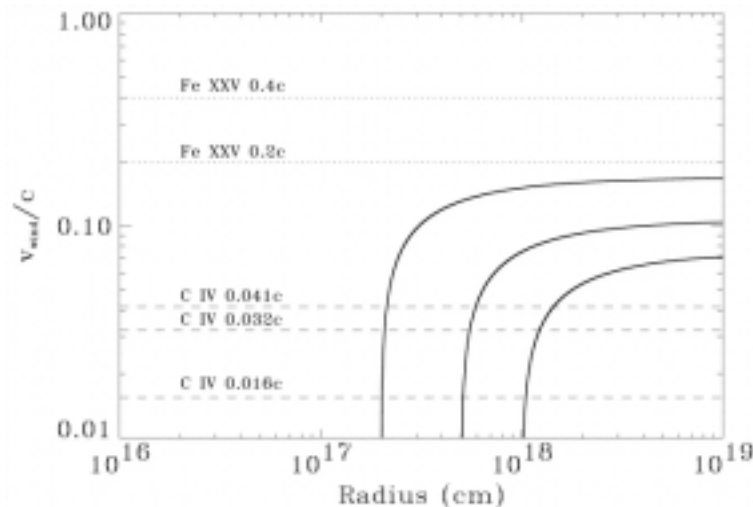
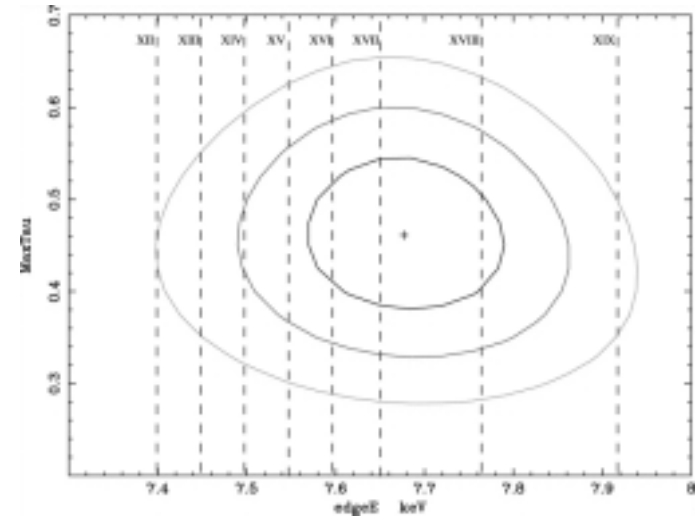
Chartas et al. 2002 - Chandra



Hasinger et al. 2002 - XMM



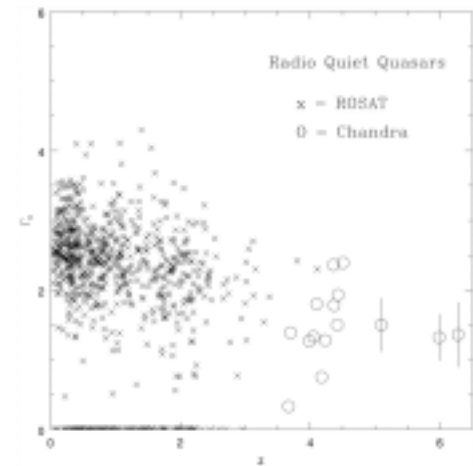
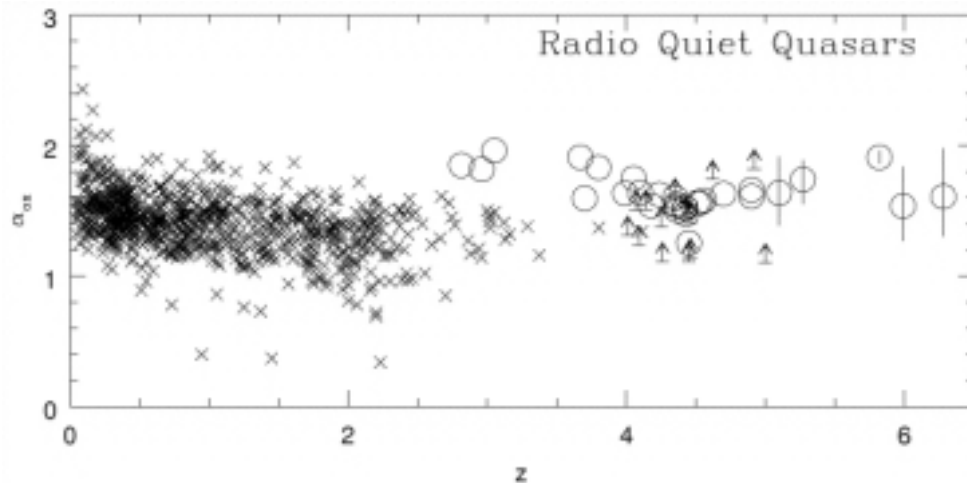
Chandra lines at 8.1 and 9.8 keV (rest frame). Bulk velocities of x-ray BALs are $\sim 0.2c$ and $\sim 0.4c$



XMM line at ~ 7.6 keV. Inferred column density of $N_H \sim 10^{23} \text{ cm}^{-2}$

Survey of RQ high- z quasars

Bechtold et al. 2003, ApJ



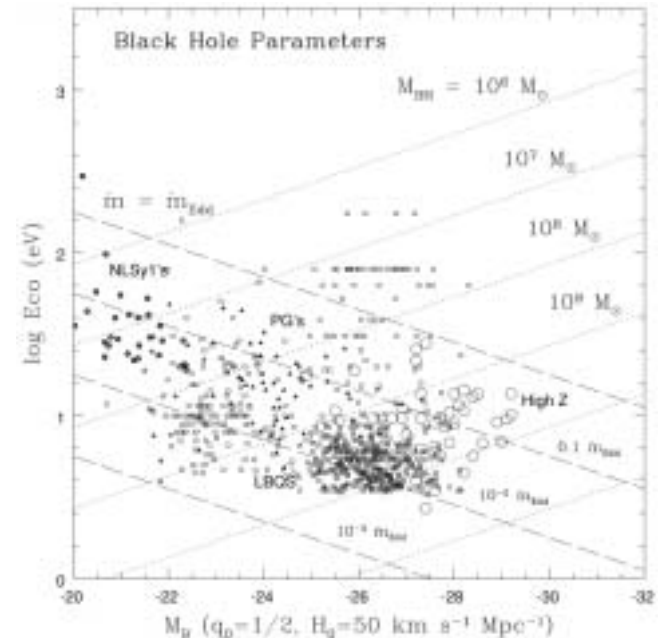
Detected 16/17 radio-quiet quasars

Redshifts between 3.70 and 6.28

More x-ray quiet than low-redshift quasars

Spectral index flatter than low-redshift quasars

Derive black hole mass of $\sim 10^{10}$ solar masses



Quasar jets / Radio Galaxies

Knots and hot spots in radio jets - synchrotron, thermal, synchrotron self-Compton (SSC) emission, or IC scatt.

SSC: Cygnus A and 3C 295; IC scattering of CMB photons - 3C 273; synchrotron - M87

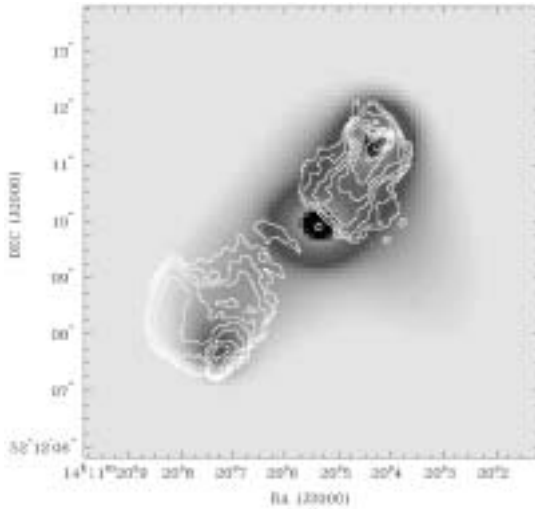


M87 - synchrotron radiation (Wilson & Yang 2002)

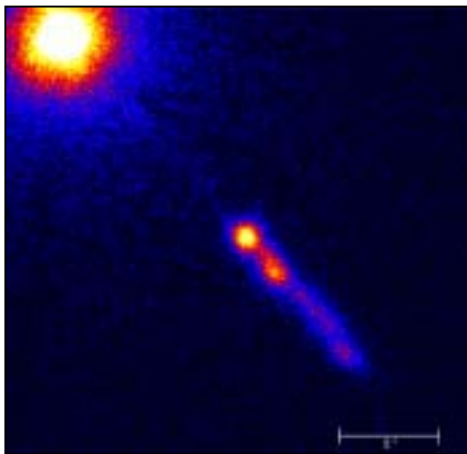


Centaurus A - x-ray and radio knots offset from each other - (Kraft et al. 2002)

A Gallery of X-ray jets (2000-2002)

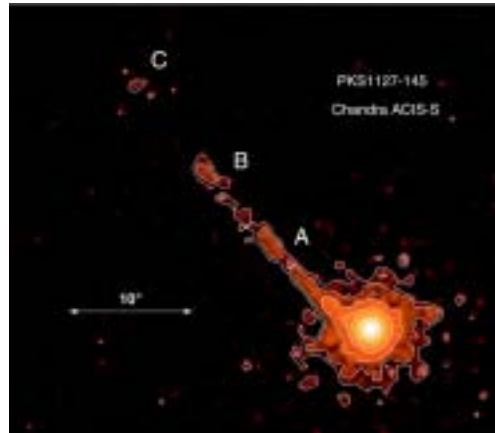


3C 295 - SSC model preferred (Harris et al. 2000)

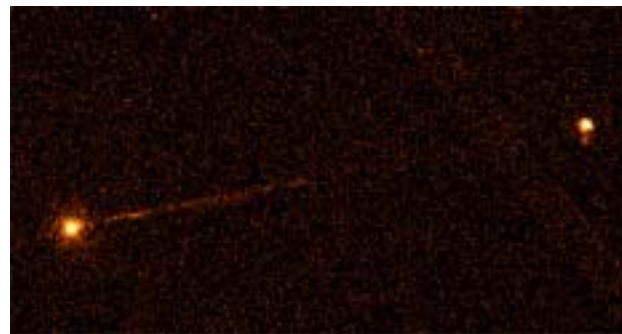


3C 273 - IC scattering of CMB (Sambruna et al. 2001)

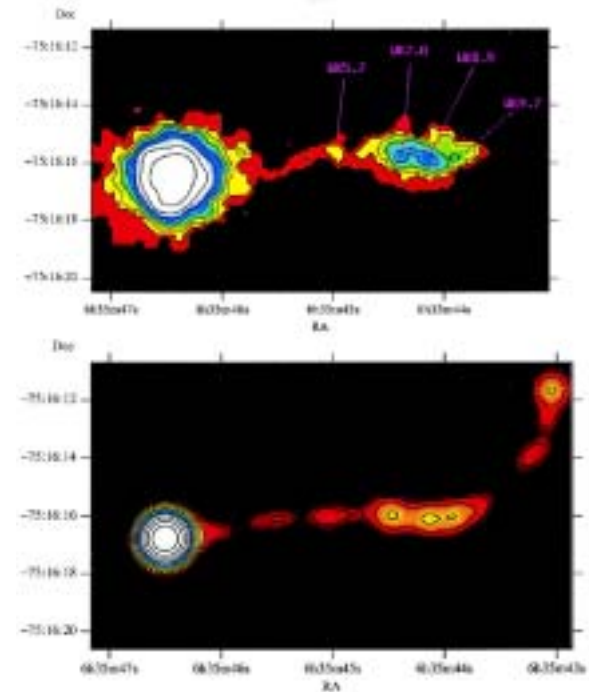
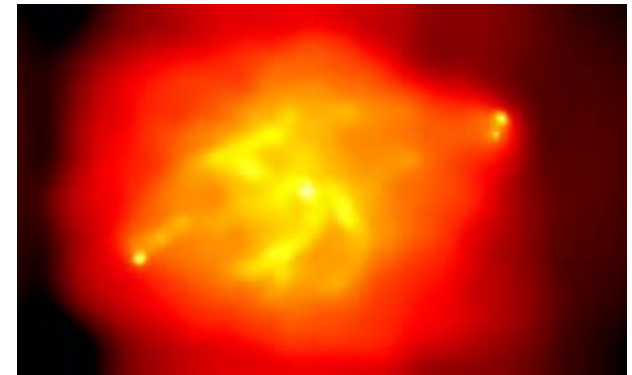
Cygnus A - radio hot spots detected in x-rays; SSC models (Wilson et al. 2000)



PKS 1127-145 - 330 kpc (Siemiginowska et al. 2002)



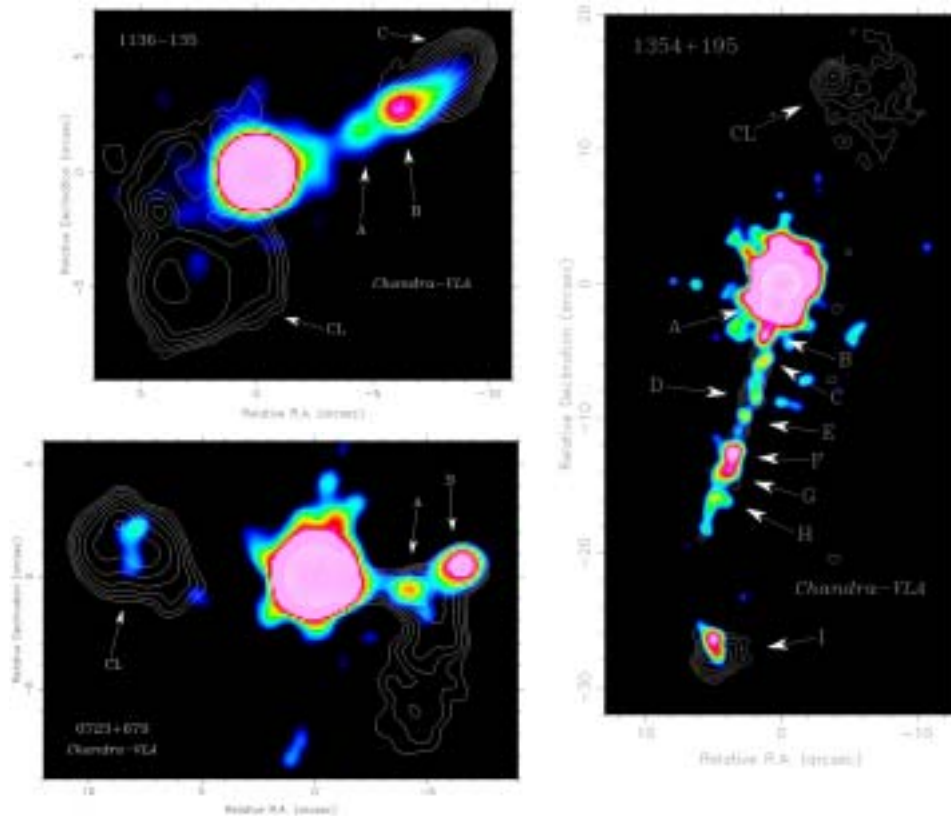
Pictor A - morphology of western hot spot similar to radio and optical (Wilson et al. 2001)



PKS 0637 - kpc sized jet similar to radio jet (Chartas et al. 2000)

Surveys of radio jets / radio galaxies

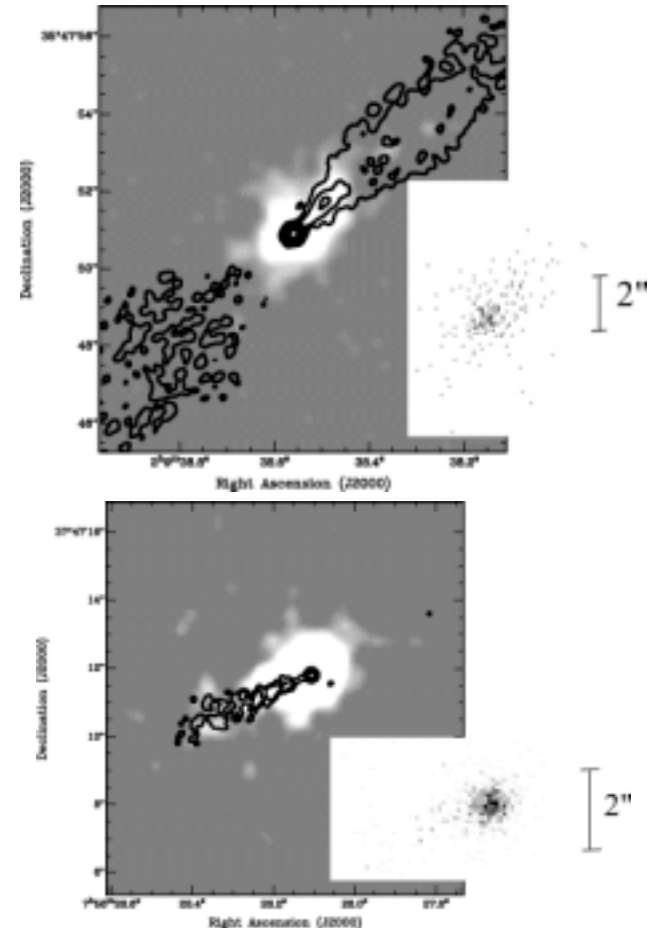
Sambruna et al. 2002



X-ray emission from extragalactic jets is common

Generally, IC of CMB photons

Worrall et al. 2001



X-ray jets are common in low power radio galaxies

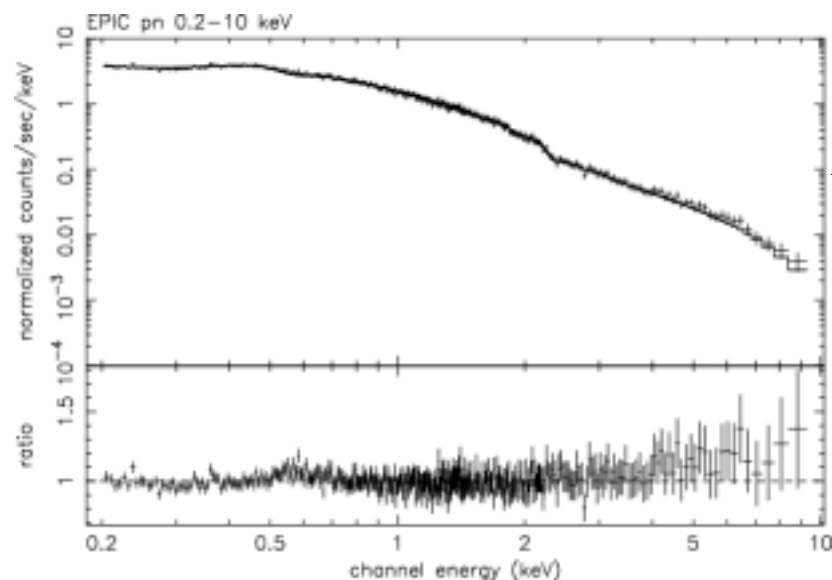
BL Lacs

- Strong x-ray variability
- Smooth, featureless spectra
- Lack of x-ray spectral features?
- High polarization
- Relativistically beamed jet close to the line of sight
- Unified schemes - parent population thought to be FR 1 radio sources
- LBLs and HBLs - single population?

MS 0737+7441

Boller et al. 2001, A&A

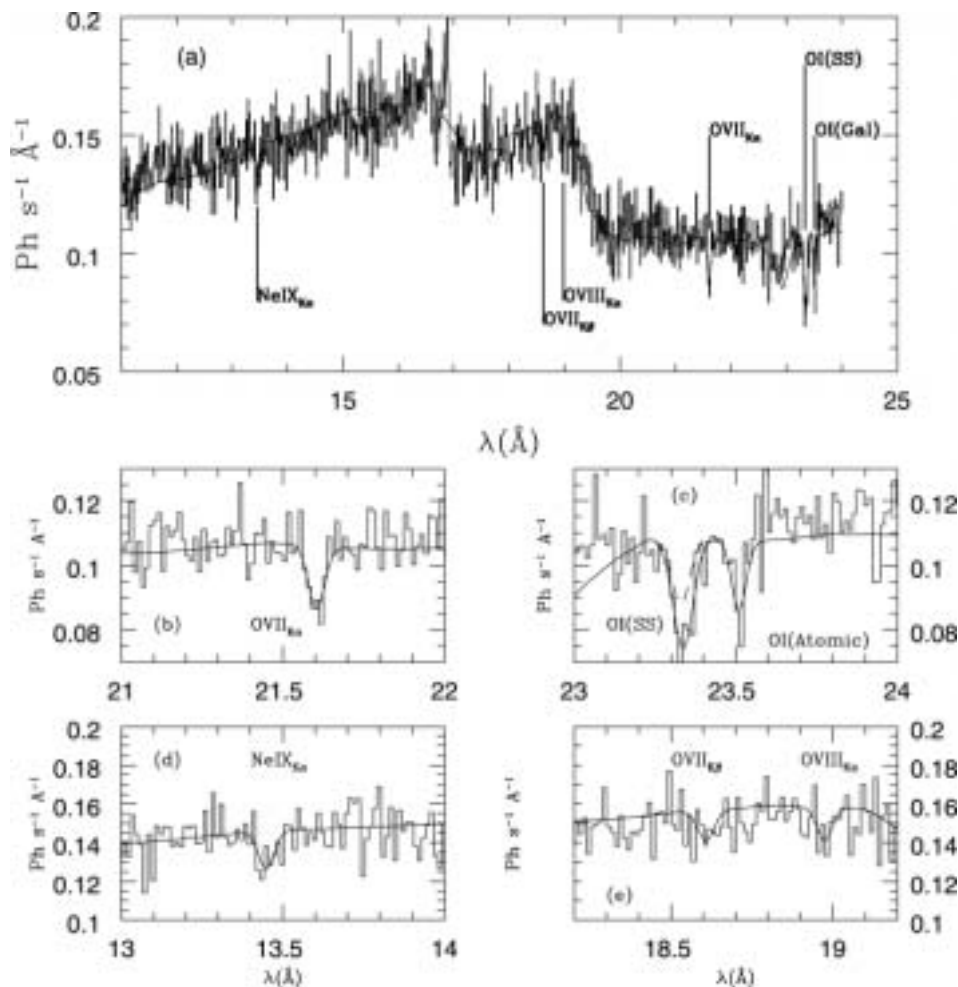
Simple power law, $\Gamma = 2.3$



PKS 2155-304

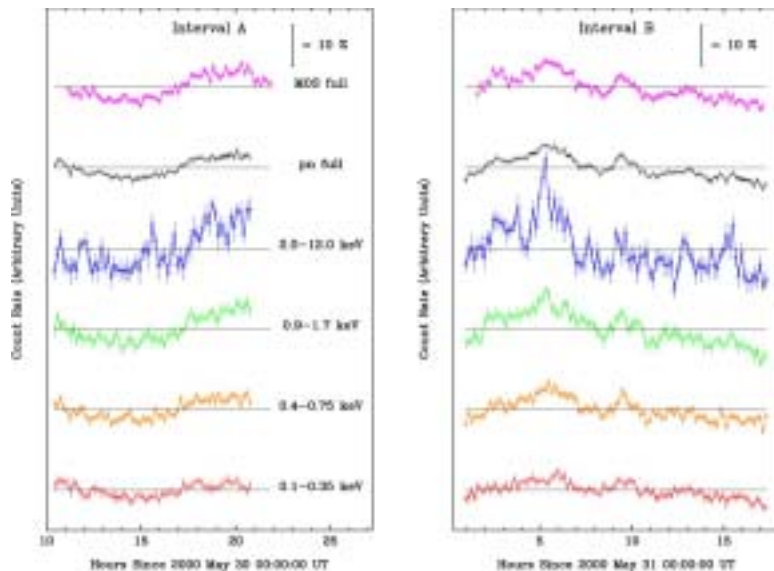
Nicastro et al. 2002, ApJ

Detect resonant absorption from warm/hot gas in our Galaxy or the local IGM. Unresolved O VII $K\alpha$ and Ne IX $K\alpha$



PKS 2155-304

Edelson et al.
2001, ApJ



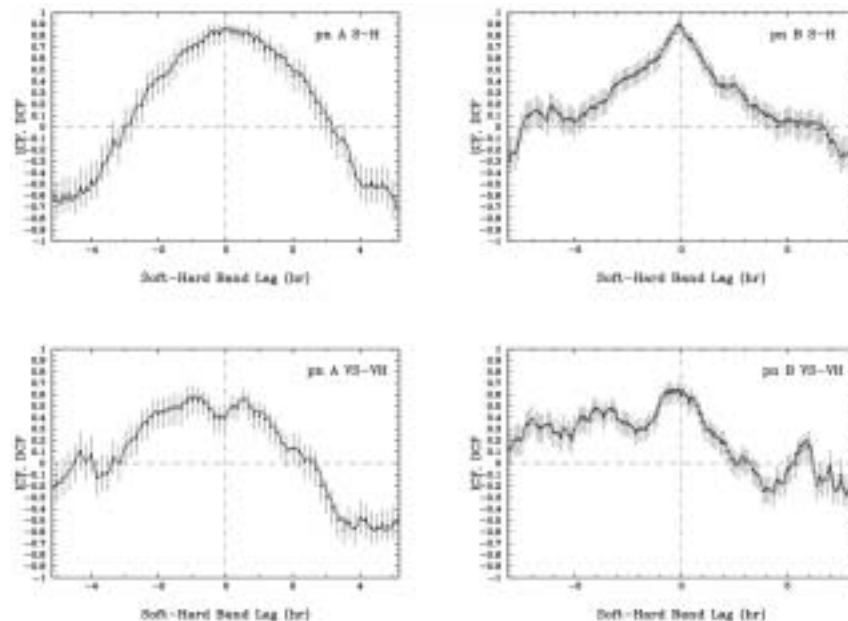
XMM light curves

Strongest variability in the hardest bands

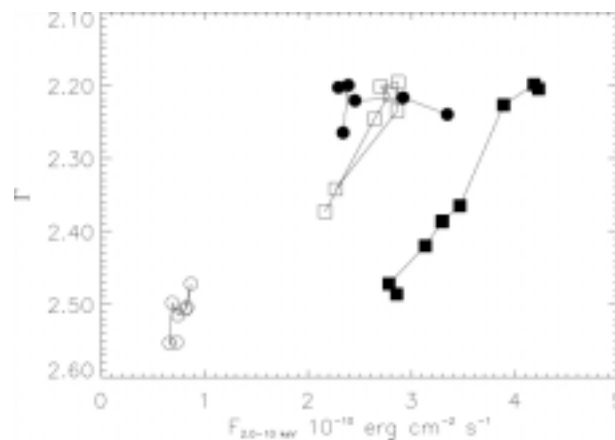
All CCFs consistent with zero lag. Similar for Markarian 421 (Sembay et al. 2002, ApJ)

Previous claims for lags may be due to satellite orbital interruptions

Limit to magnetic field strength: $B\delta^{1/3} > \sim 2.5$ G



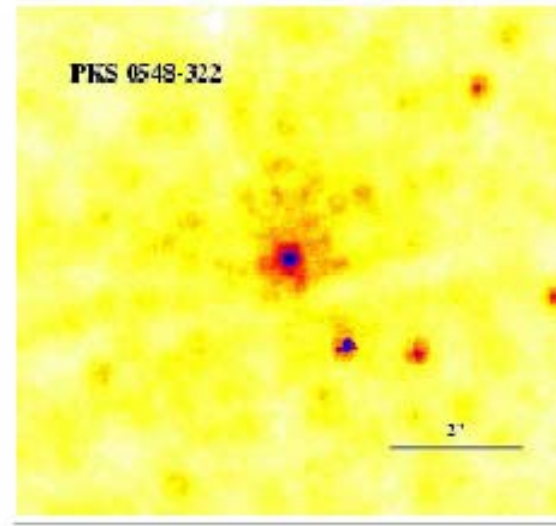
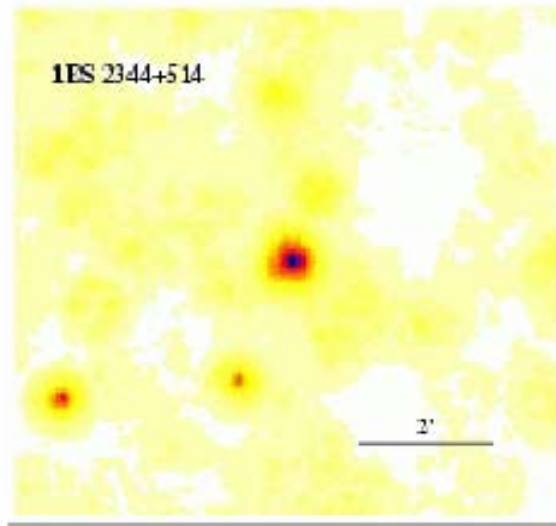
CCFs for bands H/S (top) and VH/VS (bottom)



Mrk 421: Sembay et al. 2002

Parent population

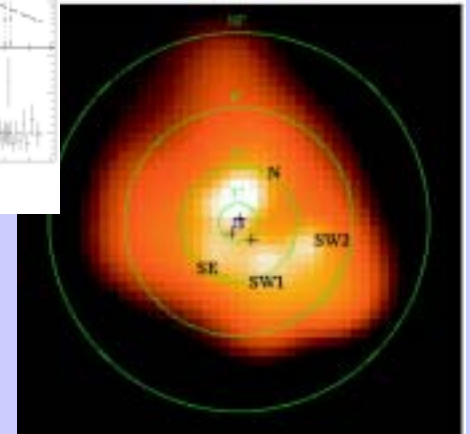
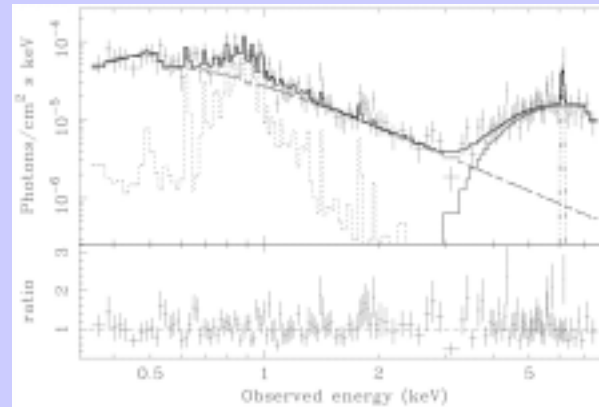
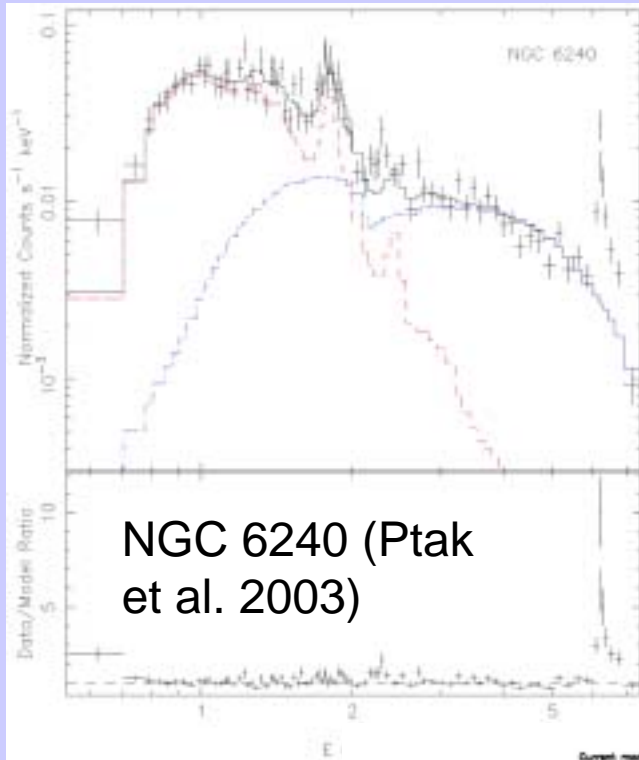
Donato et al. 2003, A&A



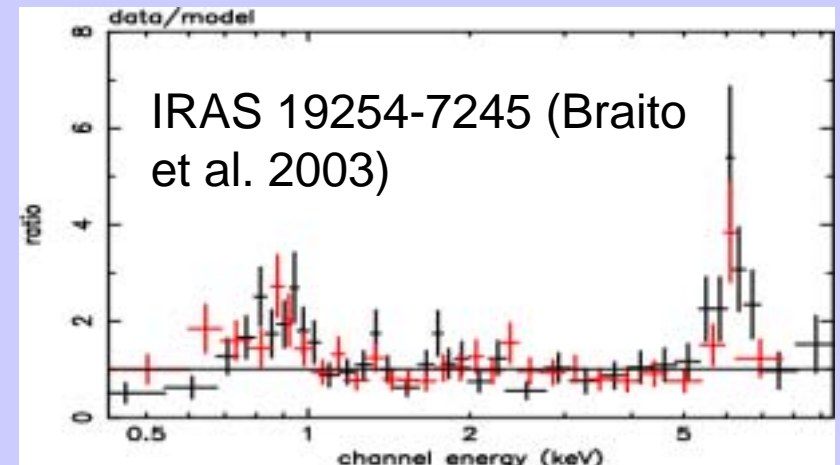
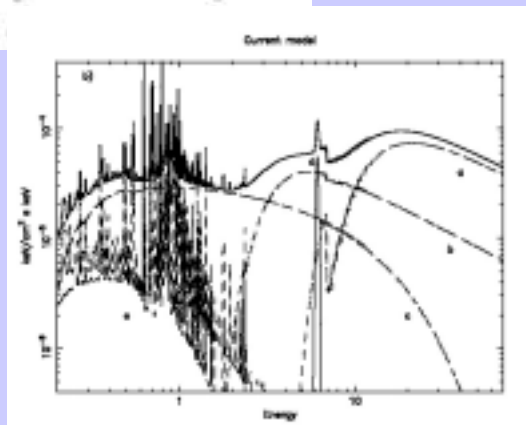
Diffuse x-ray emission consistent with elliptical galaxies

Support models for radio-loud AGN, unifying BL Lacs and FR1 radio galaxies - these are the galaxies associated with the edge-on jet.

ULIRGs and AGN



Mrk 231
(Braitto et al.
2003) FeK
EW~300 eV

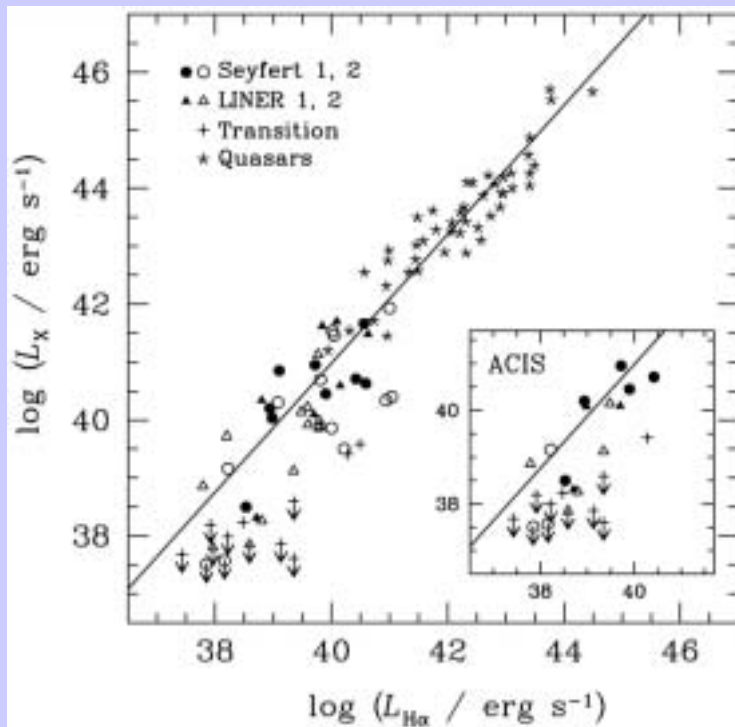


LLAGN/LINERs

Low luminosity AGN are more common than originally thought.

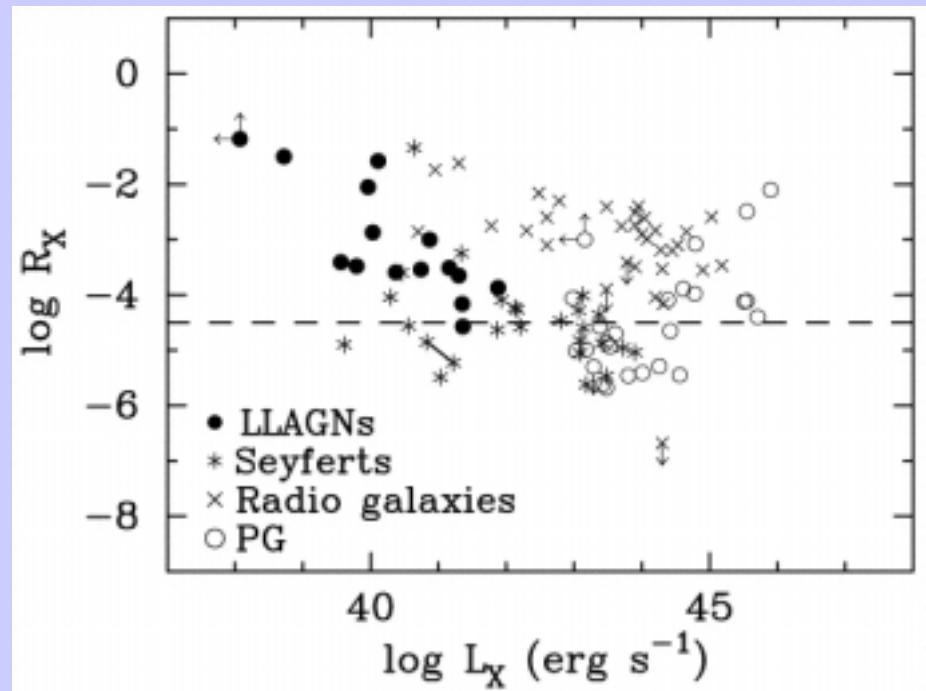
It's easier to find them in x-ray than in optical surveys.

Ho et al. 2001, ApJ



62% of nearby galaxies have compact x-ray nuclear source

Terashima and Wilson 2003, ApJ



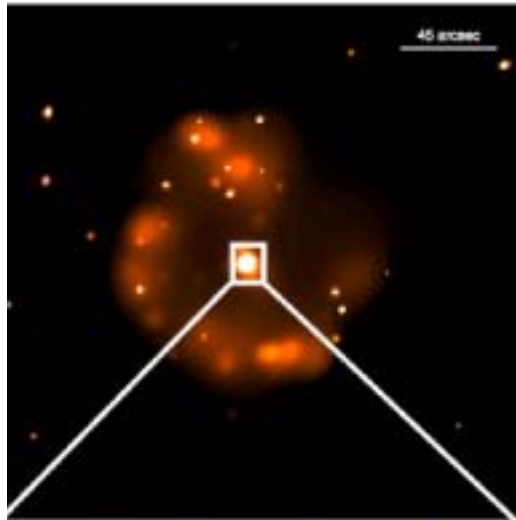
Large fraction of LLAGNs are radio loud

NGC 4303

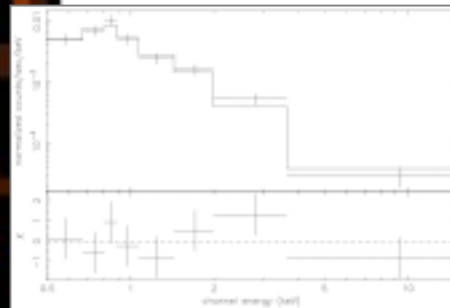
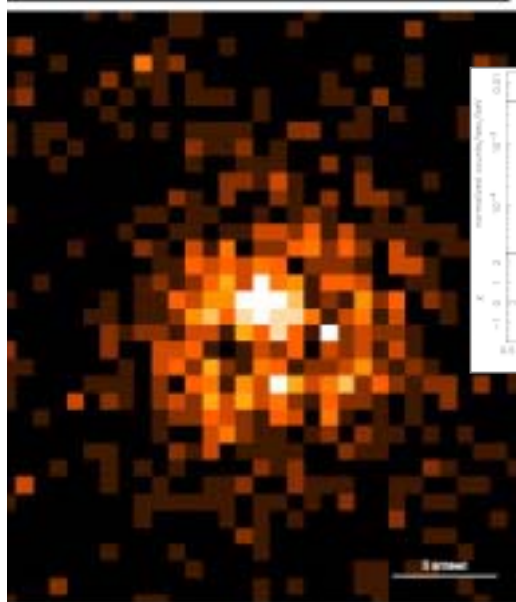
Jimenez-Bailon et al. 2003

Nuclear ULXs?

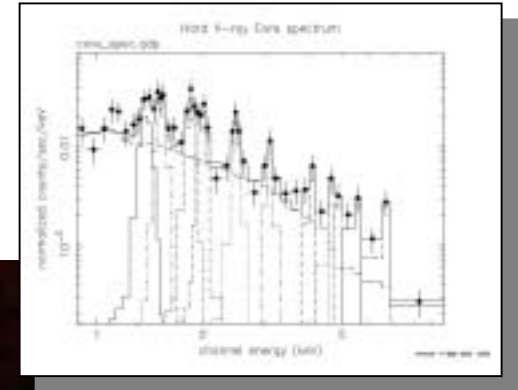
NGC 253



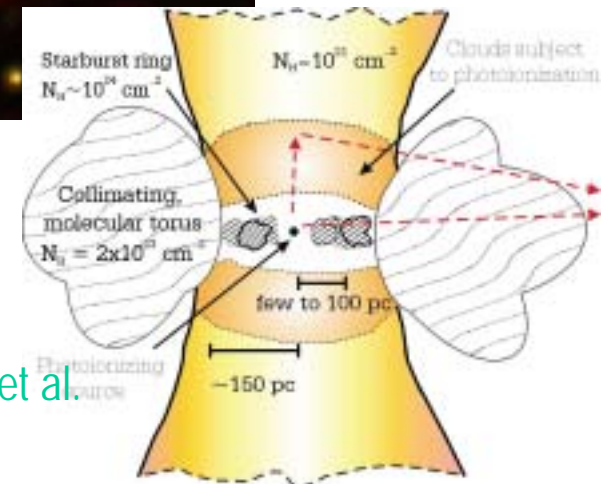
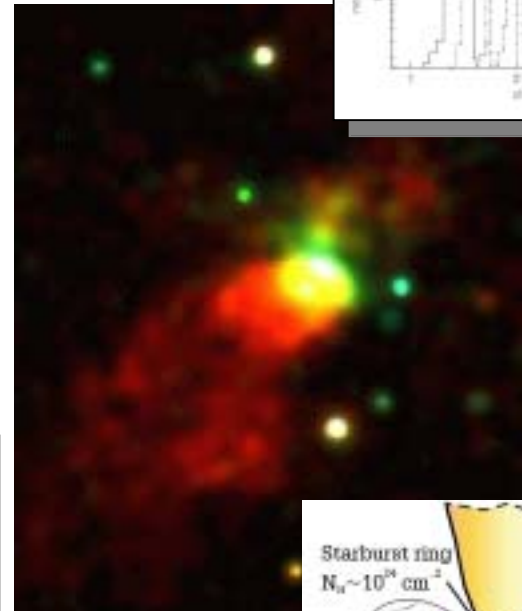
Super
starcluster and
LLAGN or ULX
at the galaxy
core, $L_x \sim 10^{39}$ erg/s



Core spectrum



Core spectrum
 $L \sim 10^{39}$ erg/s
photoionizing
ULX or LLAGN



Weaver et al.
2002

Summary

- Fe K lines of all types. Many possibilities for diagnostics, including accretion disks. Fe K emission from NLR, BLR, torus is common.
- NLSY1s - high accretion rates, ionized disks
- Multiphase warm absorber is an expanding shell of gas with outflow velocities of ~ 500 km/s and $N_H \sim \text{few } 10^{21} - 10^{22} \text{ cm}^{-2}$
- Extended x-ray emission in Seyferts dominated by photoionization
- Relativistic outflows in BAL QSOs
- Still trying to reconcile UV and x-ray absorbers in AGN
- Observations support models unifying BL Lacs and FR1 radio gals.
- Extragalactic x-ray jets are common, multiple mechanisms for x-rays
- Starbursts can obscure central AGN - making Sy 1s into Sy 2s?.
- LLAGN are more common than previously thought. “Nuclear ULXs”?
- AGN are significant in at least some ULIRGs